

# “Formulation of policy Surface Hydrologic Modeling and Analyzing Watershed Hydrologic Response to Land cover Change”

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## Abstract:

We are experiencing unprecedented environmental degradation accompanied by complex interactions between urbanization and global environment and climate change on the lives of natives of a particular geographical region influences the overall health status of an individual increasing our understanding of these interaction will involve more active collaboration between the expert from ecological, social and health science. Health professionals and environmental have a vital contributory role in preventing and reducing the health effect of global environmental change.

Urban flooding is the most frequently occurring disaster in rapidly urbanizing cities. Rapid urbanization in general, is characterized by an increase in the total impervious surface area, which means less soil cover for the storm water to infiltrate and a greater volume of runoff from the area in case of a storm event. This increased volume of surface runoff, if not drained, results in urban flooding. Urban flooding can cause serious economic and environmental damages by disrupting transportation and spreading pollution. It is therefore, essential to understand the cause, behavior and effects of urban flooding so as to minimize the risks and costs associated with urban floods. This research provides an insight into surface hydrologic modeling. It also provides an overview of calibration against DEM resolution and hydraulic conductivity values. Finally, it provides an understanding of watershed hydrologic response to different land covers with various Manning's roughness values.

## 1. INTRODUCTION

The study of water fluxes in urban watersheds has gained importance in recent years because of growing concerns about water sustainability and droughts in urban areas with subsequent economic, public-health and flooding impacts. Flooding in urban areas is a serious and growing problem. Hydrologic models are increasingly used to simulate hydrologic processes and study flood sin complex watersheds. In urban areas, they are commonly used as a management tool and for designing storm water drainage infrastructure. Hydrologic models are simplified representations of hydrology, primarily used for understanding underlying processes and simulate potential scenarios. Hydrologic processes include precipitation, interception, depression storage, surface runoff, subsurface runoff, evapotranspiration, channel flow, and groundwater flow.

Hydrologic models are classified based on the aspect of the hydrological cycle they address e.g. rainfall-runoff models. Runoff models are the mathematical models that describe the rainfall-runoff relations of a rainfall catchment area. Runoff models can be used to predict increment in the surface runoff from an urban area due to change in factors governing the surface water flux.

The conceptualization of the water fluxes is essential for understanding the hydrological behavior of an urbanized catchment. Hydrologic models can simulate various fluxes (runoff) from watershed for different real and hypothetical scenarios of rainfall events. This information is vital for understanding and devising plans to reduce floods. Further, they can also be used to analyze the capacity of the existing storm water drainage infrastructure in an urban area. Modeling of storm water runoff in urban areas is complex because of heterogeneous

Land cover and changing overland flow paths due to newer constructions. However, recent advances in remote sensing and computing power have resulted in increased use of distributed numerical models to understand and study floods typically, two types of hydrologic models - lumped models and distributed models, are used to model a flood. Distributed models allow the simulation of flood in 'as realistic as possible' manner. Such models coupled with a long time-series of historical data that relates stream flows to measure past rainfall events are used to produce the discharge hydrographs from catchments. For example, a distributed model based on Green-Ampt infiltration equation and Continuity equation could be applied to estimate runoff from some selected catchments within the Back River watershed. Lumped models, however, are limited in their capacity to map the spatio-temporal behavior of floods in urban watersheds. They lack the capability to incorporate a variety of spatially varying data from different datasets on higher resolution precipitation, soil characteristics, land use etc. A universal model applicable in all types of catchment would be difficult to create as hydrologic process varies with region and even within the same region at different times. This research aims to study urban hydrology by estimating surface runoff using an event-based distributed parameter hydrologic model. The hydrologic model is developed using combination of Green-Ampt infiltration equation, Manning's equation for shallow flows, and Continuity equation. It is used to produce discharge hydrograph at the outlet of small catchments in Baltimore.

The developed model is also used to analyze the change in surface runoff volume due to land cover change.

## **OBJECTIVE OF PROPOSED RESEARCH**

The goal of this study is to understand flooding in urban areas. The main objectives of this research are as follows:

1. To develop a distributed parameter hydrologic model capable of simulating the rainfall-runoff process of an urban catchment.
2. To determine the relationship between Manning's roughness coefficient of urban surface and surface runoff using the model developed through Objective 1.

3. To provide a workflow for developing a Green-Ampt infiltration equation based on distributed parameter hydrologic model for urban catchments.

## RESEARCH MOTIVATION:

This research is undertaken for following reasons:

1. To identify the urban hydrological modeling practices.

Hydrological processes in urban catchments are different from those in natural catchments because of the changes brought about by urbanization. Natural hydrological processes, such as infiltration and overland flow are altered and new processes such as anthropogenic storm water drainage flow, flow through manholes appear. Such alterations lead to complex spatio-temporal interactions among hydrological processes. This research aims to understand some of the modeling practices and identify the practices that will reduce the uncertainties associated with hydrological modeling of urban watersheds.

2. To develop a simple physically based hydrologic model capable of simulating rainfall-runoff Process Rainfall-runoff models have been used to produce hydrographs and peak discharge values for design purposes in medium to large watersheds However, recent rainfall-runoff models are complex in their structure due to the requirement of being physically based found that the applications of several models have surpassed their limits of usability and more complex structure are being applied to the models for improved methods of representing model inputs. But at present, compared to the available data the level of model sophistication is significantly more developed

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## RESEARCH APPROACH:

1. Research approach for achieving Objective:

The first objective of model development is achieved by developing a hydrologic model that simulates the rainfall-runoff event for an urban catchment. A physically based distributed parameter hydrologic model is developed, using the Green-Ampt infiltration equation to predict the infiltration within a given catchment for a given storm event. Moreover, combination of the continuity equation and Manning's equation is used to estimate overland flow. Only one runoff generation mechanism – the surface runoff is considered to

determine the discharge from the catchment. This hydrologic model uses gridded DEM to delineate the catchment and identify the pour-point. The rainfall event and computational time is divided into a number of smaller time steps. The outflow from each grid cell for each time step is then computed by the hydrologic model and the outflow from the pour-point cell is plotted against time to obtain a discharge hydrograph from the catchment.

## 2. Research approach for achieving Objective:

This objective is achieved by changing the Manning's roughness values associated with selected pixels/regions of the catchment corresponding to different land cover change scenarios. Some examples of land cover change scenarios are changing the land cover from concrete to grassland and transformation of a residential area into a park. For each of the scenarios, discharge hydrographs is to be produced and compared to determine the relationship between Manning's roughness and surface runoff from the urban catchment.

## LITERATURE REVIEW

This chapter includes a review of the studies consulted to conduct this research. As the first objective of this research is to develop a distributed parameter hydrologic model based on Green-Ampt infiltration model, the first part of this review discusses studies on urban hydrologic modeling and the use of Green-Ampt infiltration based hydrologic models, which is followed by an overview of the studies on the causes of urban flash flooding. A brief history of flash flooding in the two study sites of this research is also provided.

### Urban hydrologic modeling

Hydrologic models are the watershed models that are used to study the rainfall-runoff relation of a watershed in connection to geography and geology. Watershed models have been extensively used from early times for flood control and drainage of storm water. Recent advances in the field of satellite technology and remote sensing, GIS and database management systems have significantly improved the ability of urban watershed models to predict urban hydrology. These improvements in urban watershed models have made them an increasingly attractive tool to manage urban water systems for public health and sanitation, flood protection and more recently, for environmental protection. Despite the advances, many important challenges in urban watershed modeling still remain unresolved. The global trend of urbanization has meant that water management paradigms have evolved from the simple objective of just securing the water supply and flood protection, to a combined management strategy of the various urban water system components i.e. water treatment, distribution, recycling, sewerage and storm drainage etc. Thus, there is a need for the newer urban watershed models to be able to address these management strategies while also ensuring that the models are reliable, usable, affordable, resilient, and, adoptable to address the uncertainties of climate change and urbanization Modern urban hydrologic models act a tool for providing an integrated water management solution.

Integrated water management strategies use a multi-dimensional approach centered on the need for water, the policy to meet the needs and management strategies. The first dimension may consist of water elements encompassing various aspects of water quantity and quality. The second dimension may consist of water uses which include agriculture, water supply, energy generation, industry etc. Other dimensions may consist of policy to balance the supply of water amongst different users. Usable water is limited in its availability and depends on the environmental systems such as atmosphere, hydrosphere, ecosphere etc. of a particular area. The practice of managing environmental systems as a cohesive whole is a recent phenomenon and needs further research. Traditionally, water management strategies have lacked an integrated approach and considered all components independent of each other in a fragmented manner. Development of watershed models has progressed along the same path as management.

Various models are available for different parts of the urban water system, each capable of addressing some water system components to a great detail, but lacking the capability to interact with the surrounding environment. Therefore, the focus in recent times has been more towards the development of integrated watershed models that are capable of addressing issues related to integrated water resources management.

### **Historical and Current practices**

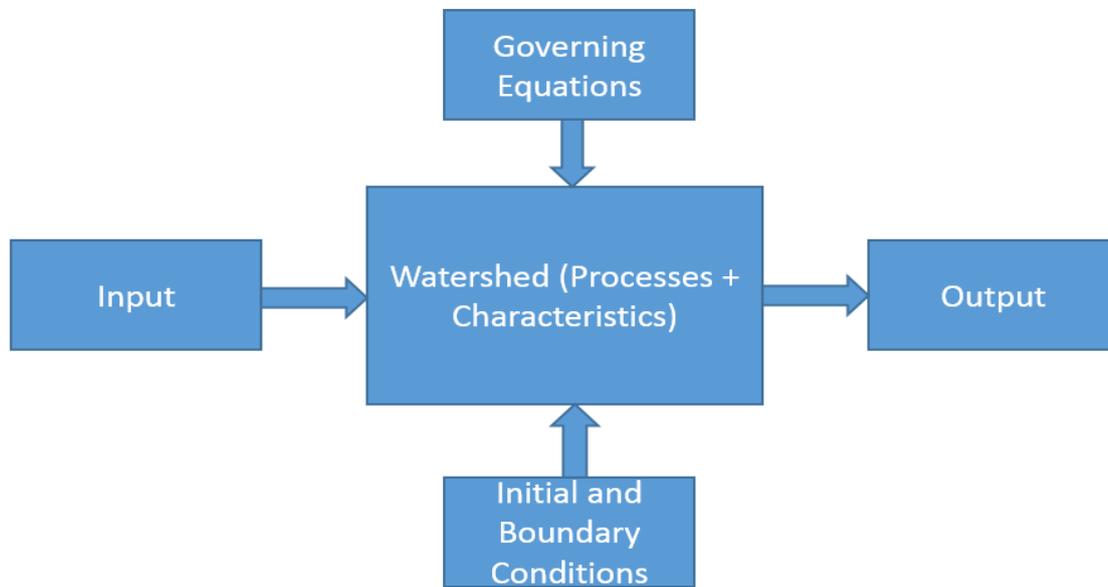
The main idea behind the development of urban watershed models was to come up with a tool that can help understand the hydrological behavior of urbanized catchments. The primary hydrological needs of urban population are availability of clean water and management of waste-water/sewage. The initial development of hydrologic models was mainly guided to address these two particular issues – drainage of excess storm water and proper evacuation of waste. As that technology related to hydrologic models grew, so did the capabilities of the models. Issues related to safety i.e. flood prediction, pollution risk assessment etc. were also addressed by the hydraulic and transport models. The need for proper drainage of storm water and wastewater was felt by the people from the earliest civilizations of the Mediterranean and the Middle East. The current urban drainage practices are based on the concepts of urban drainage developed in European and American cities in the early 1800s (Delleur, 2003). As urban population centers started growing in sizes, the need for more sophisticated means.

### **Classification of contemporary hydrologic models**

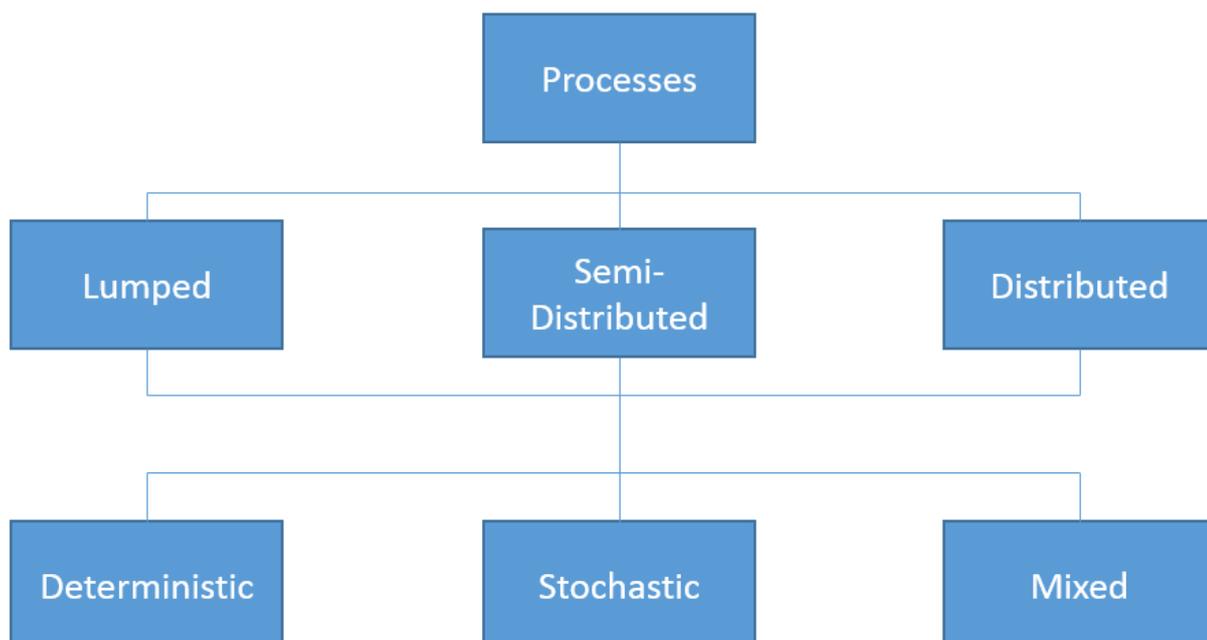
Recent hydrologic models are grouped into various categories based on the modeling approach used. Stated that watershed-scale modeling approaches are distinguished based on - the algorithm employed (empirical, conceptual, or physically-based) to develop the model, the approach used for model input or parameter specification (stochastic or deterministic), and, the spatial representation (lumped or distributed). Ever since the development of the Stanford Watershed model (1966), a number of hydrologic models have been developed (Singh, 1989). Different types of models were developed for different purposes. While many models share structural similarity, some are different. Classified the hydrologic models into different groups as follows:

### Process based classification

A hydrologic model has five components – 1) system (watershed) geometry, 2) input, 3) initial & boundary conditions, 4) governing equations, and 5) output as shown in figure

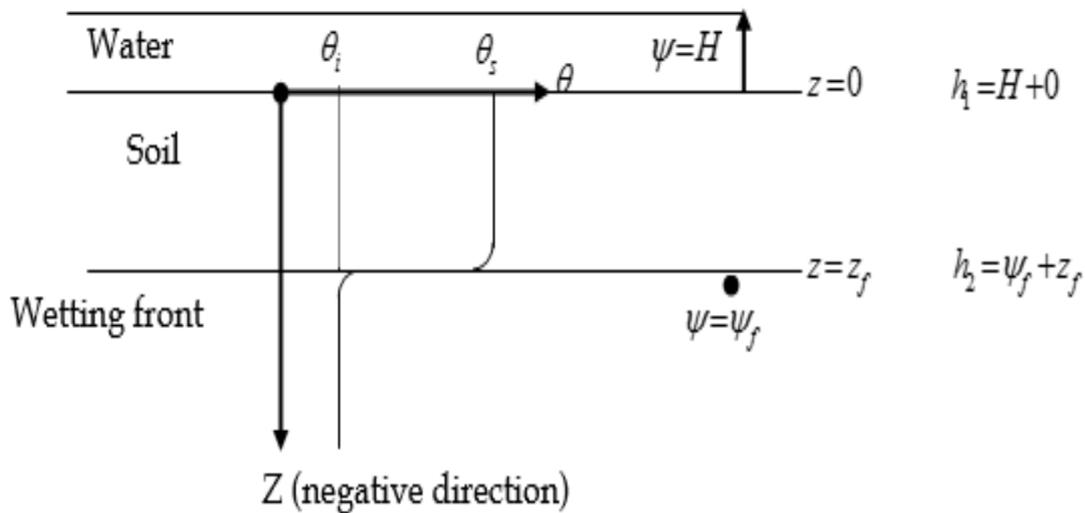


Different combinations of model components are done to produce different types of models. The fifth component (output) is affected by the watershed processes and characteristics. Watershed processes include all the hydrologic process that affects the output. Based on the watershed processes and characteristics, the models are described as lumped or distributed, deterministic or stochastic, or mixed as shown in figure



In lumped models, the watershed is delineated as a single entity and the spatial variability of the processes within it aren't taken into account. Some examples of lumped models are HYMO

The simplicity and accuracy of Green-Ampt infiltration model allows for its use in infiltration computation in rainfall-runoff modeling.



In Green Ampt method of infiltration estimation, instantaneous infiltration rate is defined as a function of hydraulic conductivity of the given soil (K), soil suction head ( $\psi$ ), and the initial amount of infiltrated water already present in the soil ( $\Delta\theta$ ) as given in equation (1).

$$F_t = K \left( \frac{\psi \cdot \Delta\theta}{I_c} + 1 \right) \dots \dots \dots 1$$

Where  $F_t$  is the rate of infiltration in cm/hr. at time t, K is the effective hydraulic conductivity of the transmission zone in cm/hr.,  $\psi$  is the wetting front suction head in cm,  $\Delta\theta$  is the available soil moisture content and  $I_c$  is the cumulative infiltration in cm.

The advantages of the Green-Ampt infiltration model are:

1. Wetting front location can be computed because of the availability of analytical solution.
2. Soil properties can be characterized by using less numbers of parameters i.e. only two.
3. It is a widely tested infiltration model. Further, it is simple and self-sufficient to handle various field conditions.
4. "The model is sufficient to represent the soil spatial heterogeneity in a lumped manner."

## DESCRIPTION OF AREA/TOOLS USED

### STUDY AREA

The study area is PATAN catchment of Narmada basin 30kms far from Jabalpur district of the Madhya Pradesh in India, according to Survey of India (SOI). The elevation of the Patan town is 652 m from the sea level. 32°C The average temperature of this watershed is 32°C. Patan watershed is to be found between 23°00'N to 23°45'N and 79°25' E to 80°30' E. The main river of this watershed is Heran (Hiran) that is a tributary of the Narmada Basin. The outlet point of this watershed is at 23.3011°N latitude and 79.6636°E longitude.

Water Balance Study of Narmada River Basin an Integrated Approach Using Remote Sensing and GIS Tools and Techniques .High inhabitant's expansion, fast urbanization and climate change along with the irregular frequency and intensity of rainfall cause difficulty in appropriate water management and storage plans. Therefore, there is an urgent need of evaluation of water resources at various scales, as it plays a primary role in the sustainability of livelihood and regional economics throughout the world. It is the primary safeguard against drought and plays a central role in food security at local and national as well as global levels. Modern researches in civil engineering using satellite based data and GIS techniques have created a very promising research tool for hydrological investigation and interpretation of landscape. Surface hydrological indications are one of the promising scientific tools for assessment and management of water resources.

Hydrological models are of two types, out of which one is lumped model, which assumes that whole grid is homogenous, all physical properties are same everywhere and do not use physical formulas to derive water balance components and the other is distributed model, in which equal weightage has been given to all properties lying in the area to derive the water balance components of the river .

SWAT, is a continuous-time, semi-distributed, process based river basin model, developed to evaluate the effects of alternative management decisions on water resources and nonpoint-source pollution in large river basins described the expanding global use of SWAT as well as several subsequent releases of the model. provided further description of SWAT, including SWAT version 2005, and also presented an in-depth overview of over 250 SWAT-related applications that were performed worldwide. It was developed to predict impact of land management practices on water, sediment yield, and agricultural chemical yield such as nitrogen, phosphorus and biological oxygen demand, chemical oxygen demand, runoff modeling, water balances modeling of large basin. For the calibration analysis of this model Sequential Uncertainty Fitting (SUFI-2) program, linked with Arc GIS

Many other methods were used in past to simulate hydrology and soils, land use and management, also several models were developed to simulate single storm events using a square grid representation of spatial variability (Young et al., 1987; Beasley et al., 1980). However, many of these models did not

consider subsurface flow, ET or plant growth. Continuous models were also developed but generally lacked sufficient spatial detail.

There is a need for hydrological research of the Narmada Basin to support improved catchment management programs that safeguard the degradation of soil and water resources in various governing states. The lack of decision support tools and limitation of data concerning weather, hydrological, topographic, soil and land use are factors that significantly hinder research and development in the area. The main objective of this study was to do water balance study and prediction of stream flow in the Upper and Middle Narmada River Basin of India, which can be used for understanding the effects of future development and management actions.

Plain. Lying in the northern extremity of the Deccan plateau, the basin covers large areas in the States of Madhya Pradesh, Gujarat and a comparatively smaller area in Maharashtra and Chhattisgarh. Study area lies between the geographical extent of north  $21.25^{\circ}$  to  $23.875^{\circ}$  latitude and east  $73.625^{\circ}$  to  $81.8125^{\circ}$  longitude, In present study an attempt has been done to simulate the impact of land and water use in Upper and Middle Narmada River Basin, using SWAT (Soil and Water Assessment Tool). For analyzing the influence of topographic, land use, soil and climatic condition; digital elevation model of SRTM, multispectral satellite data of Land sat 8, soil data from NBSS & LUP and long term meteorological data was used, respectively. Automatic watershed delineation has been done by using SRTM DEM. Model calibration and validation is done by using SUFI-2 of SWAT CUP to optimize the output so that it matches the observed discharge, available at

Garudeshwar gauging station. To check the performance of the model, five parameters were used. The final solution has been reached when the two statistical parameters such as coefficient of determination and coefficient of efficiency (NS), reaches constant values.

**4.RESULTS & ANALYSIS** It has been clearly observed from LULC map (Figure 2)

that the Upper and Middle Narmada River Basin is a deciduous forest dominated area followed by an agricultural land which contribute to the significant economic importance of the area.

It has been found from slope map (Figure 4) that most of the catchment area has general smooth slope and it covers about 60–70% of the total catchment area but the rest of region especially near the origin of river the area falls under steep slope category. This high-altitude area contributes to a significant amount of soil erosion as well as high run-off, especially during monsoon periods may be partly due to inadequate management practices. Clay and Loamy are the most dominating soil categories found in this catchment.

## 4. PROPOSED WORK

Identification of climate change signals in Narmada basin through statistical analysis of historical climate variables. Modeling the watershed hydrology in the Narmada basin by physical based large scale hydrological model

Software used

Swat Model

Swat model is a soil water assessment tool. The model was produced by Jeff Arnold for the (USDA) farming exploration benefit.

Swat is multitasking program .Swat was developed to predict the effect of land management practice on water, sediments and sediment yield. Swat is a physically based model that requires two kinds of information i.e. spatial information and meteorological data.

I) Spatial Data

- DEM (GRID FORMAT)
- LAND USE MAP (GRID FORMAT)
- SOIL MAP (GRID FORMAT)

II) Meteorological data

- DAILY RAINFALL (mm)
- Daily relative humidity data (optional)
- Daily wind speed data (optional)
- Daily solar radiation data

All the physical procedures like sediment development and runoff development are precisely displayed by swat utilizing this information and therefore a restoration can be achieved without contributing time and economy. The different hydrological models generated by the model are precipitation, infiltration, sub surface run-off, evapotranspiration, level stream and percolation. The model uses a typical structure as hydrological model (HYMO) [William and Hann 1978] for runoff measurement. Particular model

That contributed in the progress of swat model were CREAMS (Chemical Runoff and Erosion from Agricultural Management

System) [Leonard et.al 1987] and EPIC (Erosion Productivity Impact Calculator)

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